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STUDYING THE SPATIAL DISTRIBUTION OF INTERSTELLAR DUST

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I. Introduction

The spatial distribution of interstellar dust reflects both interstellar dynamics and the processes which form and destroy dust in the interstellar medium. The IRAS survey, because of its high sensitivity to thermal emission from dust in the infrared, provides new approaches to determining the spatial distribution of the dust. We report here the initial results of an attempt to use the IRAS data to probe the spatial distribution of dust - by searching for thermal emission from dust in the vicinity of bright stars.

It can easily be shown that a bright, luminous star embedded in a region of "average" interstellar density, i.e. n(H) = 1, and "typical" dust-to-gas ratio, will heat the nearby dust and produce infrared emission readily detectable from IRAS. Consider for example a B3 star at a distance of 50pc from the earth. At a radial distance of 0.25 pc from the star (angular distance 0.25° as seen from earth), the heat input into the interstellar dust from this star is 1.1×10^{-21} erg cm^{-3} s^{-1} H-atom^{-1}, more than 200 times that due to the "mean" interstellar radiation field. Assuming n(H) = 1 and a path length of 0.25 pc through the material within 0.25 pc of the star, the reradiated infrared luminosity due to this heat input will be 6.6×10^{-5} erg cm^{-2} sr^{-1} s^{-1}. If 50% of this reradiated power lies in either of the two long wavelength IRAS bands, the resulting surface brightness will be 1-3MJy/sr, detectable by IRAS in regions where the background is smooth, due to the large number of pixels involved.

II. Results to Date

The above analysis has motivated us to search for diffuse infrared emission in the vicinity of bright, luminous stars, in order to assess the probability with which they are associated with interstellar dust clouds in certain density ranges. We began with a list of 25 stars selected on the basis of high visible brightness or high ultraviolet brightness, with $|b| > 15°$. The $60\mu m$ and $100\mu m$ IRAS Sky Flux plates from HCONS 1 & 2 (resolution 6 arcmin) were examined in a search for infrared emission associated with these stars. In five of the twenty-five cases, extended infrared emission was found close to or at the position of the star. In each case, this emission shows $60\mu m/100\mu m$ flux ratio appreciably higher than that which characterizes the diffuse emission elsewhere on the same plate. The higher color temperature indicates that the infrared emission is due to dust heated by the star rather than background or foreground "cirrus" clouds.

III. Analysis

We list below the properties of the diffuse infrared emission associated with these five stars. α Lyr (Vega) is included in the table as a comparison object, known to have a very cool circumstellar dust shell, and one of the IRAS standard point sources, α Boo (Arcturus), is also listed. The table gives the peak surface brightness (I_{peak}) of the emission at the location of the star, with the background subtracted (in MJy/sr). The background is found by taking a ring around the area used for the summation and finding the mean of the lowest 25% of the values. This avoids the problems of nearby sources of emission and of stripes, and since the areas involved are small, the assumption of a single value for the background is acceptable. The flux density, with the background subtracted, is summed over a region usually 22 arcmin by 22 arcmin ($\sum I_{net}$ in Jy). The values are shown in brackets when the emission peak is not precisely centred on the source position. For α Vir two boxes were used to sum the emission, one centred on the $12\mu m$ source and one on the $100\mu m$ source. One box was used for δ Sco, but its size was increased to 48 arcmin by 38 arcmin to accomodate the extended emission at $100\mu m$. The $60\mu m/100\mu m$ flux density ratio is shown in two forms. The subscript "net" means that the preceeding two rows of summed background subtracted flux are divided to give the ratio. The subscript "sub" means that the two maps with the backgound subtracted from each were divided and the value of an appropriate pixel given. The same ratio for cirrus is 0.2 (Weiland et al., 1986). The numbers in brackets are the temperatures derived from the ratio, assuming a blackbody. The ratio of the infrared luminosity to the stellar luminosity at earth is given, showing how small an optical depth is detected.

Also given is the heating rate 1 parsec from the star (Γ). The stellar input spectra are derived from Kurucz (1979) models (a blackbody is used for α Boo). These spectra are then folded through the absorption properties of dust in the model by Mathis, Mezger and Panagia (1983) to determine the heat input, assuming the

dust is optically thin. The canonical relationship between extinction and hydrogen column density is assumed, $E_{B-V} = N_H/6\times10^{21}$.

IV. Conclusions

These preliminary results show that this technique - which relies on finding infrared emission associated with randomly selected stars - can ultimately be used to study the distribution of dust in the ISM.

The density of the cloud producing the infrared emission may be derived by assuming that the dust is at its projected distance from the star and that the heating is due to the star's (known) radiation field. The heating radiation will be folded into a Draine (1985) grain model, and the number of emitting grains adjusted to reproduce the observed energy distribution. We note that this technique is capable in principle of detecting dust densities much lower than those typical of the cirrus clouds, because we are looking preferentially at regions near stars where the heating flux is far higher than the diffuse radiation field which produces the cirrus emission.

References

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Notes for the Table

α Vir is also classified as B1III-IV. The fluxes for α Vir in brackets show that the flux given is not centred on the star, but about 14 arcmin away. The $12\mu m/25\mu m$ map shows a single peak at the stellar position, showing the star dominates the emission here. The $60\mu m/100\mu m$ shows two features, one at the stellar position and one at the peak of the $100\mu m$ flux. The flux ratios include both the star and the dust.

For δ Sco the peak $12\mu m$ flux from the star is not coincident with the peak of the $100\mu m$ flux map. Van Buren and McCray (1988) suggest the longer wavelength emission is a bow shock associated with the star. In the $12\mu m/25\mu m$ map the star is at a peak in the ratio map, and the cool dust is near a minimum. The structure is poorly defined in the contour plot for the $60\mu m/100\mu m$ map, but the "bow shock" structure is present.

ν Sco has a companion about 40 arcsec away, which is itself double. The $12\mu m/25\mu m$ map shows a minimum in the ratio at the star's position, and there is a maximum in the $60\mu m/100\mu m$ map, as the cool dust dominates the surroundings.

π Sco is visible at all 4 wavelengths, and appears much larger than a point source.

The $12\mu m/25\mu m$ shows a minimum in the ratio at the source position, and the $60\mu m/100\mu m$ map shows a peak.
The luminosities of the stars, shown in the table, are from Allen's Astrophysical Quantities.
Γ is the heating rate 1 parsec from the star.

Star	α Vir	δ Sco	ν Sco	π Sco	η Hya	α Lyr	α Boo
Sp Type	B1III+B2V	B0.3IV	B3V+B8V	B1V+B2V	B3V	A0Va	K1IIIbp
V	0.98	2.32	4.01	2.89	4.30	0.03	–0.04
r (pc)	43	~200	33	100	~160	8	10
FWHM $60\mu m$	0.80°	0.40°	0.52°	0.26°	0.52°		
I_{peak} $12\mu m$ (MJy/sr)	3.9	2.0	1.8	4.0	0.3	17.2	422.5
I_{peak} $25\mu m$	1.0	9.0	8.6	40.0	0.9	4.1	94.6
I_{peak} $60\mu m$	(3.2)	17.0	9.6	31.7	0.3	3.8	11.8
I_{peak} $100\mu m$	(1.9)	10.4	5.1	16.1	0.3	2.9	3.0
$\sum I_{net}$ $12\mu m$ (Jy)	(35.3)	79.9	23.8	26.7	14.2	40.5	861.4
$\sum I_{net}$ $25\mu m$	(120.5)	344.9	104.8	390.6	32.6	15.1	179.0
$\sum I_{net}$ $60\mu m$	(275.8)	1184	213.6	930.1	17.2	15.3	31.1
$\sum I_{net}$ $100\mu m$	(226.2)	1173	329.9	710.8	30.6	25.4	24.9
$(60/100)_{net}$	1.2 (85)	1.0 (70)	0.7 (55)	1.3 (90)	0.6 (50)	0.6 (50)	1.3 (85)
$(60/100)_{sub}$	2.0 (150)	1.2 (85)	0.9 (65)	2.1 (180)	0.8 (60)	0.3 (40)	3.6
L_* (ergs.s^{-1})	4.10^{37}	4.10^{37}	1.10^{37}	3.10^{37}	1.10^{37}	3.10^{35}	3.10^{35}
L_{IR}/L_*	$1.8.10^{-3}$	0.18	$5.3.10^{-3}$	$4.3.10^{-2}$	$1.3.10^{-2}$	$8.3.10^{-4}$	$4.1.10^{-3}$
Γ (ergs.cm^{-3}s^{-1}n$_H^{-1}$)	4.10^{-22}	1.10^{-21}	4.10^{-22}	5.10^{-23}	4.10^{-22}	5.10^{-25}	3.10^{-25}